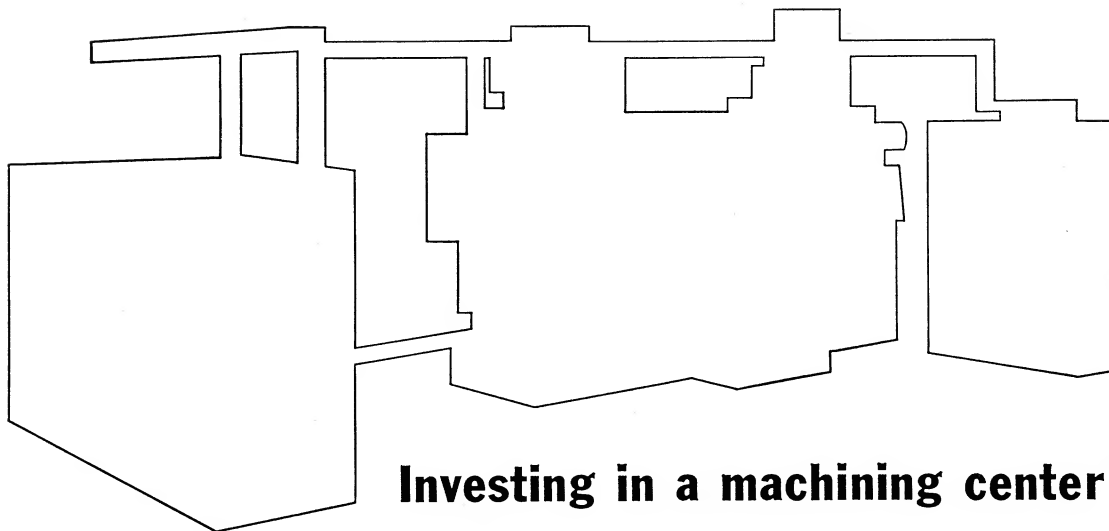
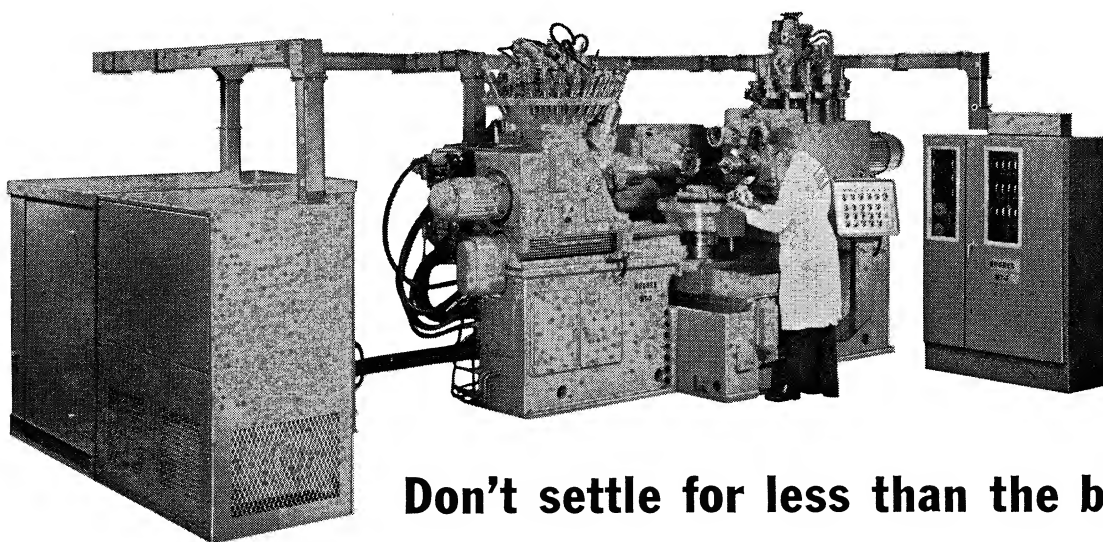




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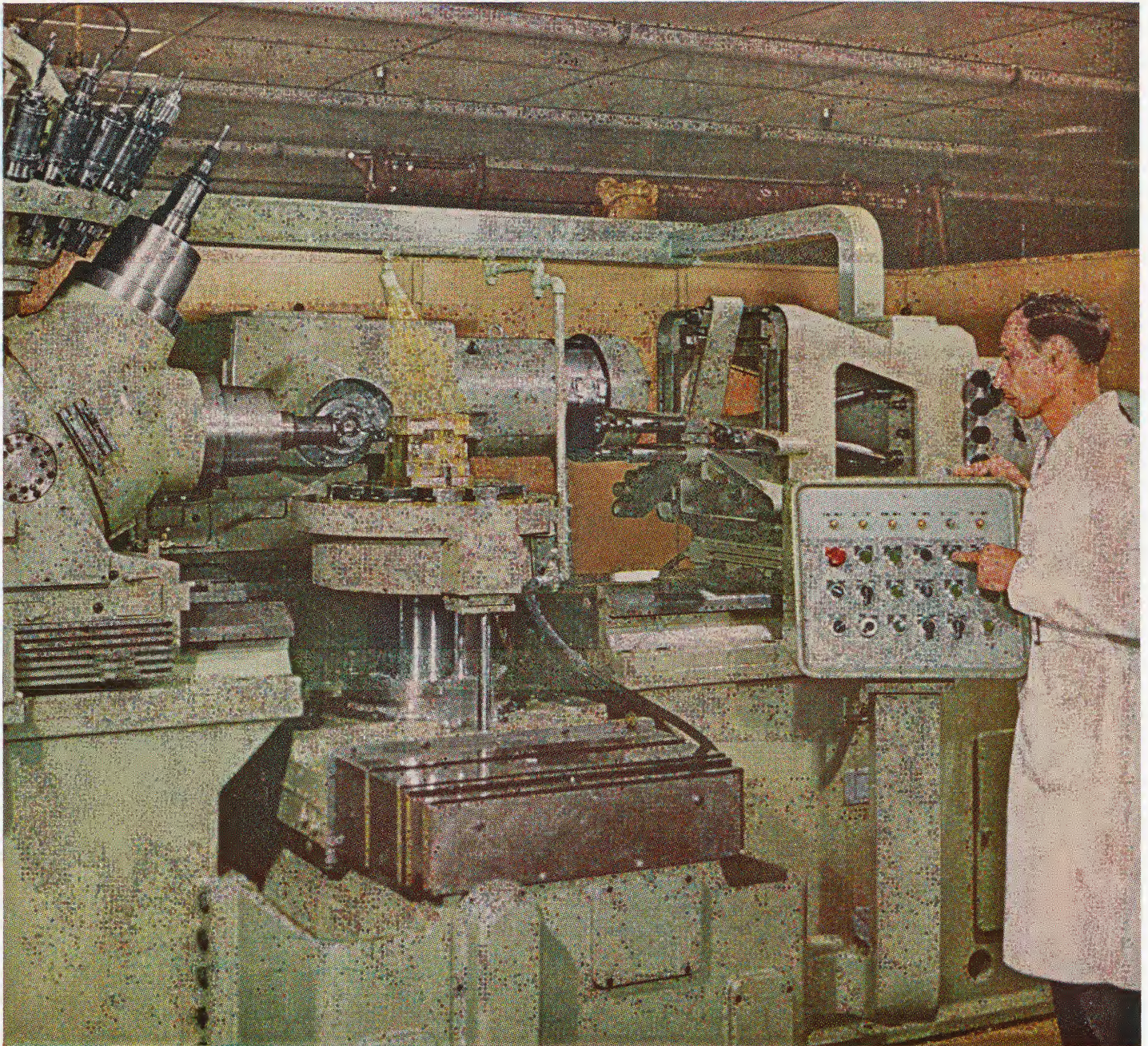


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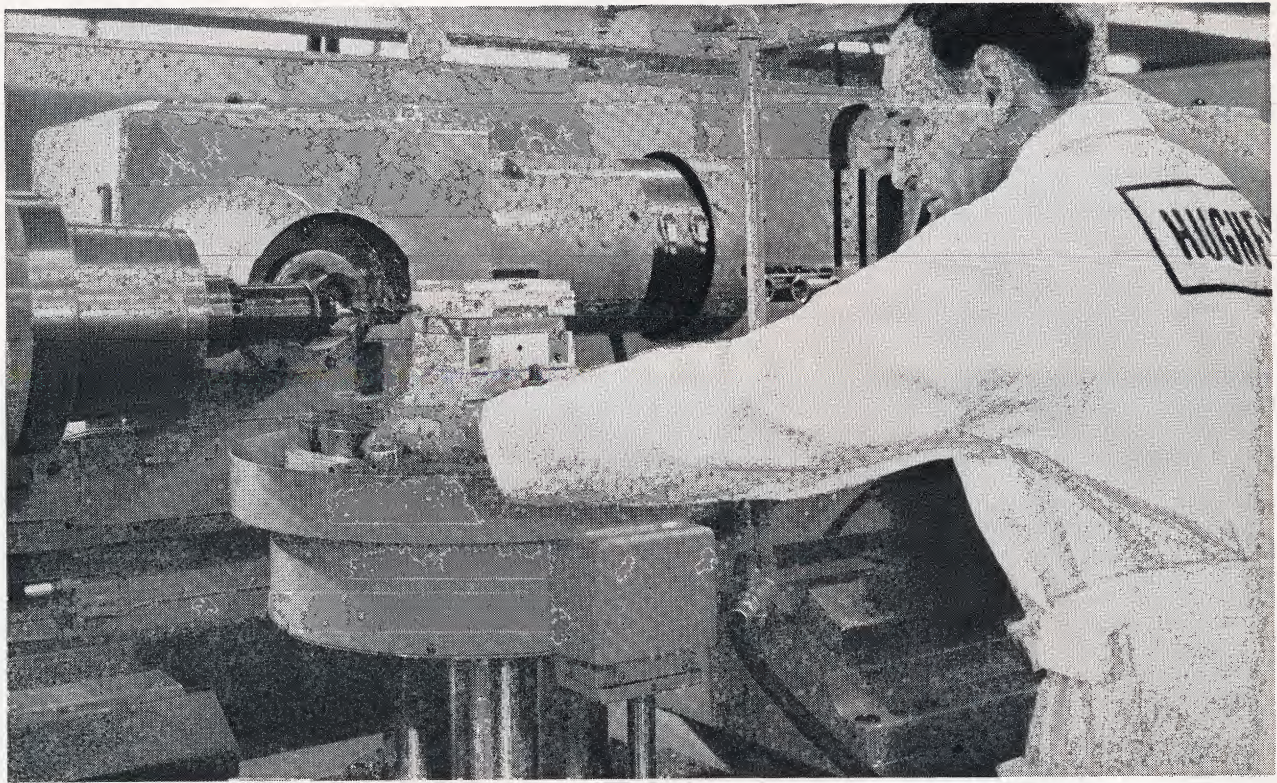
American Machinist

Metalworking Manufacturing

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One numerically controlled machine replaces five regular machines



Sixteen separate machining operations are performed on this aluminum sand casting in two setups and one holding fixture on a single numerically controlled machine. Conventional

methods required five machines with 11 setups, and five fixtures. Of three heads arranged around the positioning table (drilling, milling, and boring) only two are used.

One machine replaces five

A single numerically controlled "Machining Center" (positioning table surrounded by drilling, milling and boring heads) is doing the work of five machine tools in multiple operations on short runs of complex parts. Costs per part: about 10% that of machining by conventional methods

By George DeGroat
West Coast Editor

Numerical control is really coming into its own at Hughes Aircraft Co, where a single five-axis setup is doing the work of a vertical miller, a six-spindle drillpress, a turret lathe, a boring machine, and a tapper.

Not only that, Hughes' MT-3 "Machining Center" has cut manufacturing time per part from 1 hour to something like 18 minutes.

The Machining Center setup has in fact overcome the sky-high manufacturing costs and low profits that plague shops faced with the job of turning out short runs of complex parts. Here, numerical control has cut down (or even eliminated) the number of jigs and fixtures needed,

has reduced setup time to a bare minimum, and has virtually eliminated rejects caused by human error.

Take, for example, an aluminum casting made by Hughes in job lots of 35 pieces—a part so complex in shape that it requires 16 separate machining operations. Among them: milling four sides and the top surface; milling a step in four sides; drilling and tapping 10-32, 1/4-20, 1/2-13 and #2-65 holes; drilling, boring, reaming, and countersinking a variety of holes; end-milling a slot, and profiling openings in the part:

Conventionally, this would require five different machines, plus such tools as a milling fixture, two drill jigs, a holding fixture and a profiling templet. Design time for these tools alone would run 140

hours, and fabrication time another 295 hours.

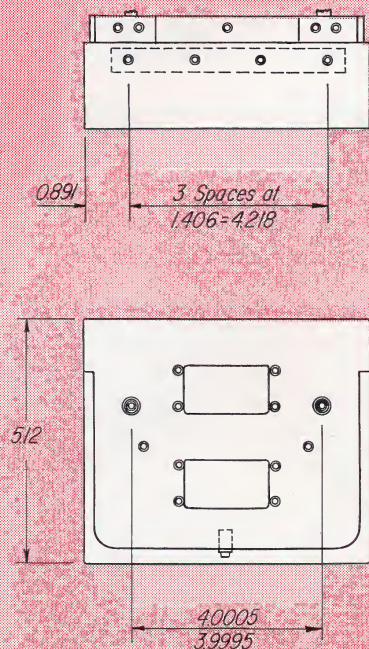
Nearly 16 hours would be needed for 11 setups, and running time for 35 pieces would be about 24 hours. Manufacturing time per part: a little over one hour.

The same job took only a little over 18 minutes per piece on the numerically controlled setup. And only two fixtures were needed (design time 32 hours and toolmaking time 56 hours for the two). Running time for performing the 16 machining operations came to slightly under 10 hours for the 35 pieces.

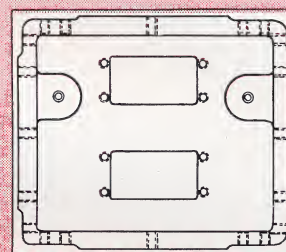
One setup for many jobs

The five-axis numerically controlled Machining Center, developed by Hughes' Industrial Systems Division, is designed to handle a variety of operations in a single setup.

The unit has three tape-controlled work heads (building-block construction) arranged around a central positioning table. One of these is a universal drilling, tapping, and boring head with storage capacity for 30 tools up to 3 1/2 in. diameter. A tool turret at this head changes tools



Complex shapes, like this aluminum casting, are efficiently machined in short-run, low-volume production with numerical control. Setup time is short and tooling is simple. In addition, repeat runs are easy to set up by using programmed tape.



automatically in accordance with programmed instruction in less than 3 seconds, while a dual-spindle arrangement at the head allows one table to be transferred to and from one spindle while the other is at work.

Tools are selected by tape commands, which position the rotating magazine—lifting the stored tool from the turret and into a ready spindle. A hydraulic cylinder moves the tool. Similarly, tools are removed from the spindle and returned to storage.

3-second tool change

At the end of the operation, the dual-spindle mount rotates 180 degrees, bringing the new tool into working position. It takes only 3 seconds to change and position a tool.

For example, drilling and reaming can be done on a series of holes simply by rotating the spindle at each location, rather than drilling all the holes and then reaming them.

A milling head behind the positioning table handles cutters up to 8 inches in diameter and has 23 speeds from 60 to 2400 rpm.

The third head, for precision boring, has 21 speeds from 100 to 3000 rpm, is also equipped for automatic tool changing and can handle up to 14 tools of 1-6 in. dia.

Operation of Hughes' Machining

Center is automatically controlled from 1-inch punched tape, from which machining instructions are read by a tape reader. The electronic numerical control system provides for point-to-point positioning in increments of 0.001 in. through velocity servos.

Taped data is delivered from the reader through a distribution system to an axis buffer storage. Here, the information is held until the beginning of a machining operation is called for by the start command or by a completion signal from the previous machining operation.

Planning and programming the Machining Center requires no special skills or auxiliary equipment. First, the sequence of operations and the method by which the part is to be held must be determined. Then data is entered on a planning sheet, including: operation number, machine head number, direction of movement; dimensional movement along head, cross and vertical axes from their previous positions; spindle speed, feed rate, tool selection, table position and direction of rotation, and any special tapping cycle that may be required.

Preparation of parts manuscripts is handled by manufacturing engineering personnel, who work directly from the part drawing.

Planning and programming a manufacturing outline for a fairly com-

plex stainless steel part, for example, takes about 40 hours, as opposed to only 16 hours for doing the job by conventional methods. But in the long run (taking the entire operation into consideration from planning to finished part), it costs about a tenth as much to produce the part on this numerically controlled machine as by conventional methods.

Another case history

As in the previous example, lot size was 35 pieces, and five machines were needed for conventional operations, plus such tooling as two milling fixtures, two lathe fixtures, and a drill jig. Conventional tool design time was 286 hours, and toolmaking time 572 hours. Nine setups were required for the five machines (14.3 hours' setup time in all), and running time for the 35 pieces was 97.2 hours.

Eleven separate machining operations included milling a flange face in four places, boring, drilling, tapping, and spotfacing.

By contrast, the numerically controlled setup required only one holding fixture, which took 16 hours to design and 36 hours to build. The one needed setup took just 2 hours, and running time was only 11.8 hours. Net result: 3.188 hours per part by conventional methods, 0.339 hour per part with the new setup. •

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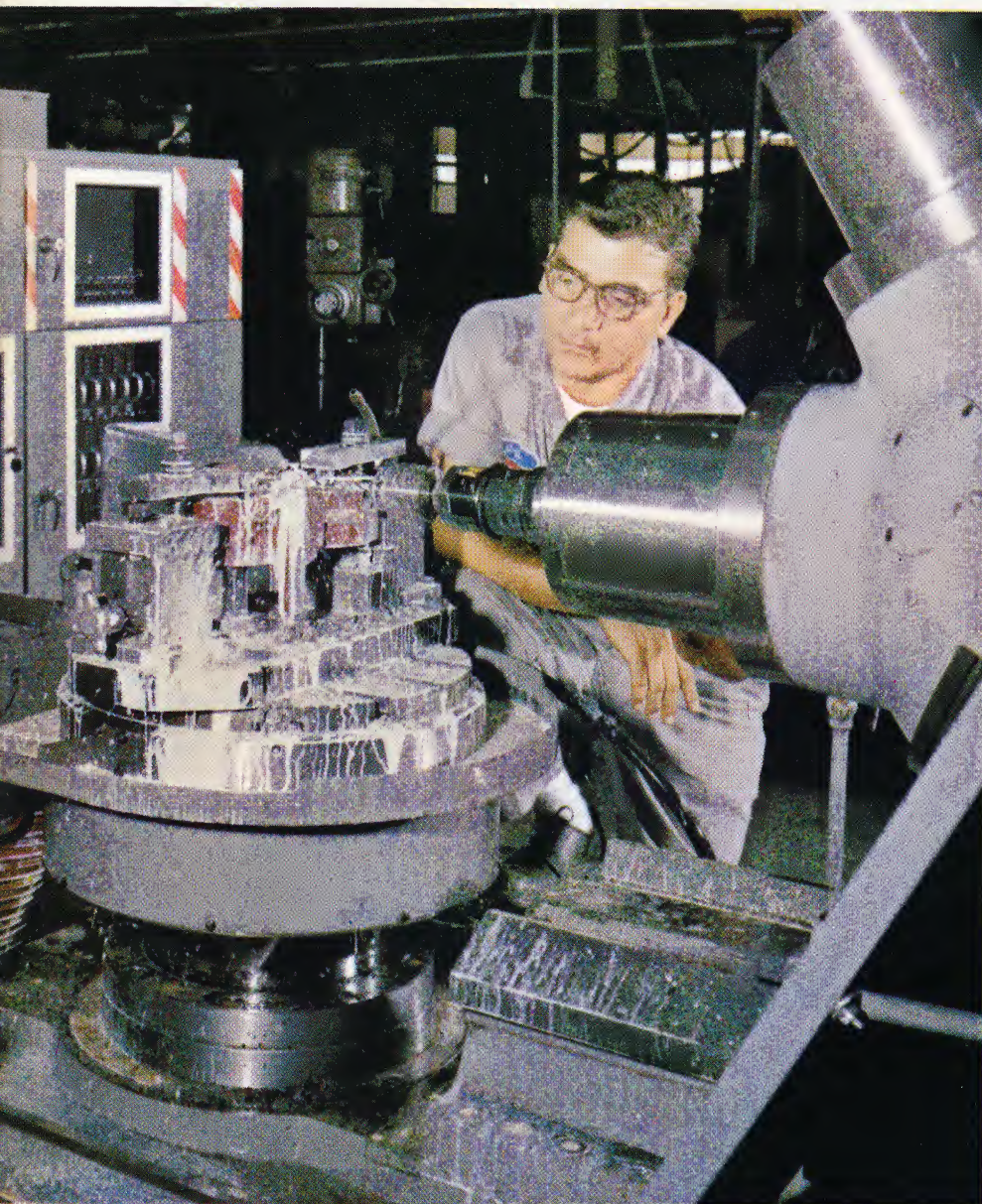
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N/C and the small company

Its first machining center nets big cost reductions for Milton Roy Co. Thorough planning and home-grown talents help start immediate payback by \$250,000 machine tool

Joseph J. Deckert,
Manufacturing Manager
Mechanical Products Division
Milton Roy Co.



Set up and running production on schedule, the machining center is the final step in the total plan, which includes competitive analysis, product redesign, management support, vendor assistance and close co-operation by Engineering and Production

● When a small company with only 150 employees moves into numerical control for the first time, with an investment of a quarter of a million dollars, and finds no discomfiting surprises, then it's proof the groundwork was well laid and the planning for n/c thorough.

This is the experience of Milton Roy Co., Philadelphia producer of fluid pumps and instrumentation, despite the nerve-shattering hearsay that abounds concerning the difficulties to expect from n/c, such as programming bottlenecks, maintenance nightmares, and generally high machine downtime.

If the company's manufacturing engineers were in the dark at all about n/c, it was that while an abundance of information was available about aluminum as a workpiece material, not enough case history data could be obtained on cast iron, 316 stainless steel and other alloys with which the company works. Consequently, some small doubt lingered about the inherent rigidity of n/c units.

But, on looking back to that August day three months ago when the unit, a Hughes MT-3 machining center, began running production, one wonders what the fuss was about. Tool, fixture and setup cost reductions are an indicated 75 per cent below conventional machining. In addition, housings for special pumps now can be produced on the machine instead of in the model shop, greatly reducing delivery time and cost. Other advantages include shortened lead times by months due to the simplification of fixturing, and tighter quality control due to the increased accuracy of dimensional relationships by holding parts in a single work fixture.

Management's interest and enthusiasm for the n/c project is best expressed in a way not found on any justification sheet. Said President Robert T. Sheen: "We will be giving our customer the fastest possible delivery by assembling our pumps from off-

the-shelf components and a bank of stock housings, the latter made possible by the speed and flexibility of n/c."

What paved the way to the orderly acquisition, installation and running-in of n/c was the completeness of justification procedures, including a competitive analysis of equipment; a plan to standardize and redesign the pump line for n/c machining, to minimize inventories, eliminate secondary operations and minimize the frequency of setups; and the close cooperation of the machine tool builder who assisted in programming and in proving tapes among countless other helpful tasks initiated in the company's behalf.

No Experiments, Please

The Milton Roy Mechanical Products Division, where the n/c machine is installed, accounts for roughly \$5 million of the company's \$6-to-7 million total volume of sales of products ranging from pumps to sophisticated instrumentation for analytical, pilot plant and medical fields. It may seem a paradox, therefore, that the company went

into n/c "big", ignoring the oft-heard suggestion that it start out on a small scale and get its feet wet with, say, a \$20,000 investment. Due to the strange facts of economic life, however, the company couldn't "afford" the smaller investment but could exceed that amount by twelve times for the reason that it buys for a specific need, not just for experimentation.

Evaluation Includes Transfer Line

The investigation into n/c began as part of a broad-based study on new equipment acquisitions. The company had just introduced the first of a new line of pumps intended to replace some industry standbys. The purpose was to improve the product with advanced features while minimizing the engineering and manufacturing expense involved, which is simply common-sense economics.

It was necessary, first, to incorporate the great variety of sizes and types of pumps produced through the years into a range of standardization which offered the same pumping capabilities to the consuming in-

dustries but reduced the number of actual designs manufactured to a relative few. N/C was simply the logical extension of the broad standardization program being carried out.

Initial equipment investigation took into account several possibilities with the objective of finding the one most suitable which would afford the best pay-out for the company. The spectrum examined ran from direct replacement of conventional machines through the n/c machining center concept to the ultimate stage of Detroit or transfer-type automation.

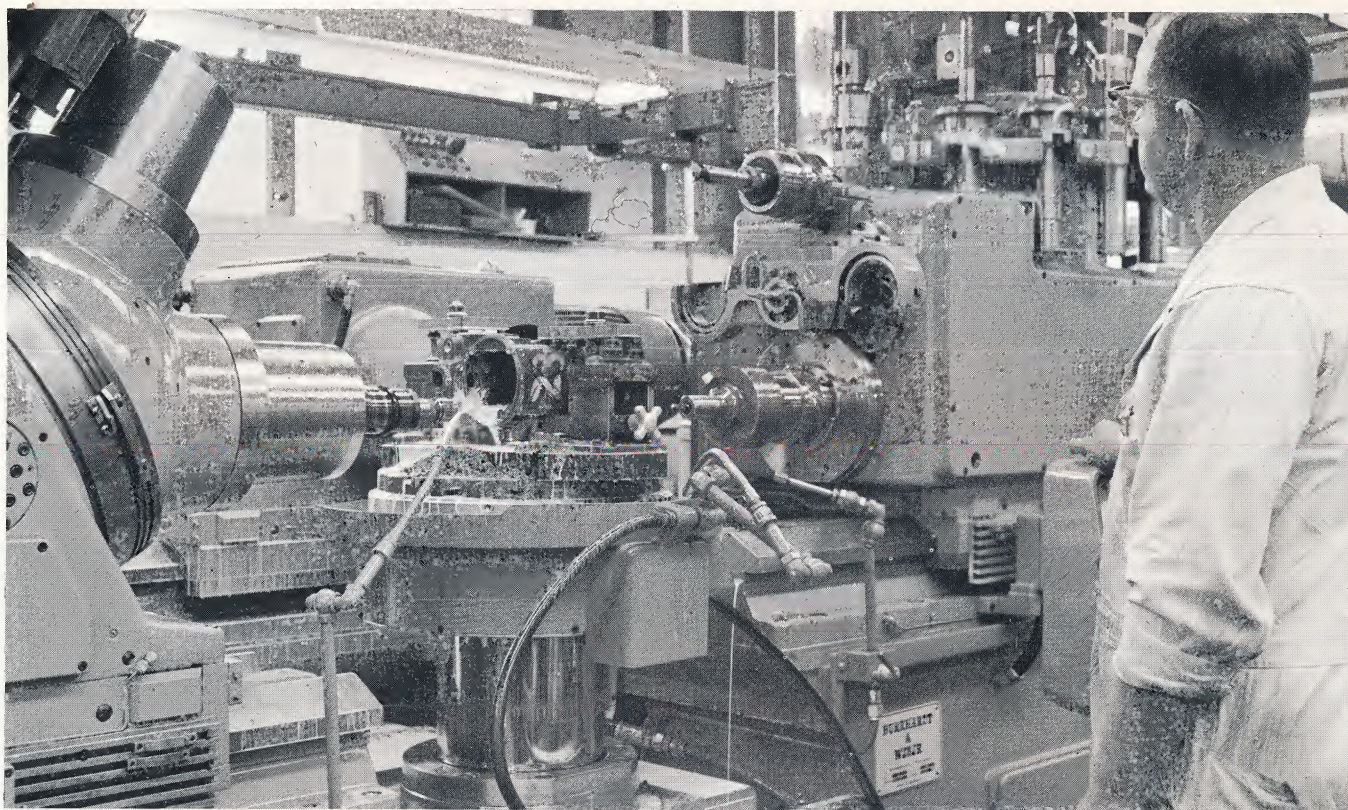
Early in the investigation, it became apparent that due to the limited product lot sizes (200 to 1700 housings per year for each of five pump configurations) envisioned under the standardization program there would be no advantage in the direct replacement of the conventional type machines in use at the time. Replacement, therefore, was discarded as a possibility and attention was centered on n/c and the transfer line.

It was thought at first that the higher

N/C MACHINING CENTER EVALUATION
(Partial List)

MACHINE FEATURE	ASSIGNED RATING VALUES	MT-3	MACH A	MACH B	MACH C	HUGHES MT-3 SPECIFICATIONS
X AXIS (cutting length)	Overall Mach. cap. } 20	12	20	18	5	24 in.
Y AXIS (cutting length)						12 in.
Z AXIS (cutting length)						19 in.
INDEX ACCURACY	20	10	10	20	10	±10 secs.
NUMBER OF SPINDLES	20	20	7	7	7	3
SPINDLE HORSEPOWER	15	10	15	12	5	7-1/2 & 10
SPINDLE DRIVE TO TOOLHOLDER KEYED	20	20	20	20	20	yes
SPINDLE SPEED RANGE--RPM	20	20	16	15	5	40 to 4000
NO. OF AUTOMATICALLY CHANGED TOOLS	20	20	18	15	5	45
MAX. DIA. OF TOOL WITHOUT DELETING OTHER TLS.	20	20	15	15	5	6 by 18 in.
TOOL CHANGE TIME	20	20	10	8	18	0 or 3 or 10 sec.
TRAVERSE HOME POS. REQ. TO CHANGE TOOLS	20	20	5	5	5	no
FEED RANGE INCHES PER MINUTE	20	18	13	20	7	.5 to 75
RAPID TRAVERSE RATE, IN. PER MIN.	20	15	20	20	20	0 to 180
PALLET CHANGER	20		20	20		no
WAY CONSTRUCTION	20	15	20	18	17	cast iron
TYPE CONSTRUCTION	20	20	18	10	5	trav. hds. & tabl
PROGRAMMING	20	20	15	18	10	incremental
RESOLUTION (smallest command mach. accepts)	10	5	10	8	5	.0001 inch
POSITIONING ACCURACY	20	10	20	18	10	±.001 in.
REPEATABLE ACCURACY	20	18	20	8	15	±.0003 in.
CONTOURING WITH THIS CONTROL	10	--	10	5	--	no
AUTOMATIC TAPE REWIND	15	15	--	15	15	yes
POSITION READOUT	20	20	18	18	18	command & actual
FEED RATE OVERRIDE	20	20	5	5	5	100% to stop
ZERO OFFSET	10	5	10	10	8	no (mech. ±.020)
PERSONNEL TRAINING COSTS		\$1,825	\$3,215	\$1,287	\$925	
TOTAL	908	760	633	646	431	

(The following departments concurred unanimously on selection of MT-3:
Manufacturing, Production Control, Tool Engineering, Industrial Engineering)



Cast-iron pump housing requires only two handlings and takes little more than a half-hour to process. Previously, 2.75 hours, floor-to-floor, irrespective of handling, were needed on a boring mill, turret lathe and five drill presses

base cost for the transfer line would be offset by greatly improved cycle times in machining and, hopefully, the amount of time necessary for change-over would be absorbed. However, this became an unrealistic area for further consideration, owing to the fact that again lot sizes are relatively modest and that flexibility and change-over time are major factors. This left the n/c machining center as the most likely production method for consideration.

In late 1963 and the first six months of 1964, extensive investigations carried on with various manufacturers of this type of equipment included long sessions with their representatives and trips to their plants. Eventually, the field narrowed to three potential vendors of equipment considered to be the optimum as to productivity and economy for Milton Roy's needs. These three manufacturers were asked for guaranteed estimates of the cycle times for seven basic pump parts which were considered the primary output of the n/c machine.

(All the while, management was kept abreast of events by an evaluation and justification manual prepared and kept up to date by Manufacturing. Since Milton Roy is a small company, matters of this magnitude are generally followed closely by top management, whose enthusiastic support and cooperation were offered to this project from the outset.)

The investigation at this point narrowed the field to two types of n/c equipment. At this time a formal presentation was

made to the board of directors. This consisted of a detailed outline of the procedures and evaluations that had been made up to that time and included films of the two machines in action. Following the meeting with the board, Manufacturing proceeded to a final decision leading to the purchase of one machine. To accomplish this, return trips were made to the two manufacturers and the machine with specifications that appeared to best meet company needs was selected.

Work Out the Details

The choice was the standard Hughes MT-3 configuration with three machining heads, including a precision boring head and a rotary indexing table which feeds vertically and horizontally. At the same time final arrangements included the requirement that tooling details, programming and tape preparation and prove-out should be done for seven basic parts by Hughes. One of these parts was selected as the acceptance part and firm commitments were made that this part should be not only tooled and programmed but that the particular work piece should be prepared and run at the Hughes plant for acceptance test prior to shipment. This test was to be repeated after the machine's installation in Milton Roy's plant. It was understood that the particular part would not only be machined to the drawing specifications, but also within a guaranteed time given by the vendor's organization.

At the time of purchase, Manufacturing

← N/C evaluation chart lists important features and specifications (about half the actual number are shown, here) of four machining centers. Each center measures against assigned point values and is rated accordingly. The chart is one of several factors that figured in final selection of the MT-3

and Engineering collaborated on detailed parts changes to facilitate manufacture by n/c. These changes, primarily aimed at reducing cycle times, included making hole diameters and thread sizes more uniform to reduce the frequency of tool changes on the machine. Currently, changes continue to be made as the need arises.

Delivery, promised for May of 1965, actually took place on May 7. Prior to actual shipment, details concerning foundation and other mounting information were provided by Hughes and a suitable foundation was constructed at the plant. On the fifth week, the machine was installed and running. Approximately three weeks after delivery, the acceptance part was being run.

Following acceptance, a programming specialist arrived from Hughes to work with company programmers on proving the programs and tapes for the balance of the parts. This was completed at the end of June and trial runs were started on July 5, 1965.

First Results: Inventories Down

With the shorter setup times and cycle times of n/c, inventories are being sharply reduced. Previously, the longer lead times occasioned by conventional machines, with the lag from one machine to another, meant that long runs had been the norm. Now, however, the application of Economical Order Quantity formulae understandably reduces the lot sizes, and eventually, the company expects to reach a point where it can approximate its actual needs in advance of the actual month required and run no more than this quantity. The result

is a reduction in average inventory both in stores and in process.

Needed: Electronics Training

The advent of n/c brought with it special requirements for maintenance, industrial engineering, programming, and tool room operations. Though the company is still in the process of adjustment, all the changes have been accomplished with the use of in-plant personnel, who required special training but were confidently up to the requirements. The company doesn't feel it is unique in finding within its organization the people qualified to learn the new skills. Instead, it feels that these skills are more likely found within a small company than in a large one because personnel frequently double up on duties and perform varied tasks rather than performing along the lines of limited specialization often found in larger companies.

A horizontal boring mill operator was the first person selected to man the n/c machine primarily because of his analytical approach to problems and the fact that he had a broad background in cutting tool preparation and maintenance.

For programmers, two industrial engineers were picked who had been handling methods and standards work. They were sent to the Hughes factory for a two-week training program and became well adapted to this new skill.

On the other hand, the maintenance electrician was highly skilled in electrical and mechanical maintenance but had no electronics background. This, admittedly, is a problem that awaits solution with further electronics training before the company is

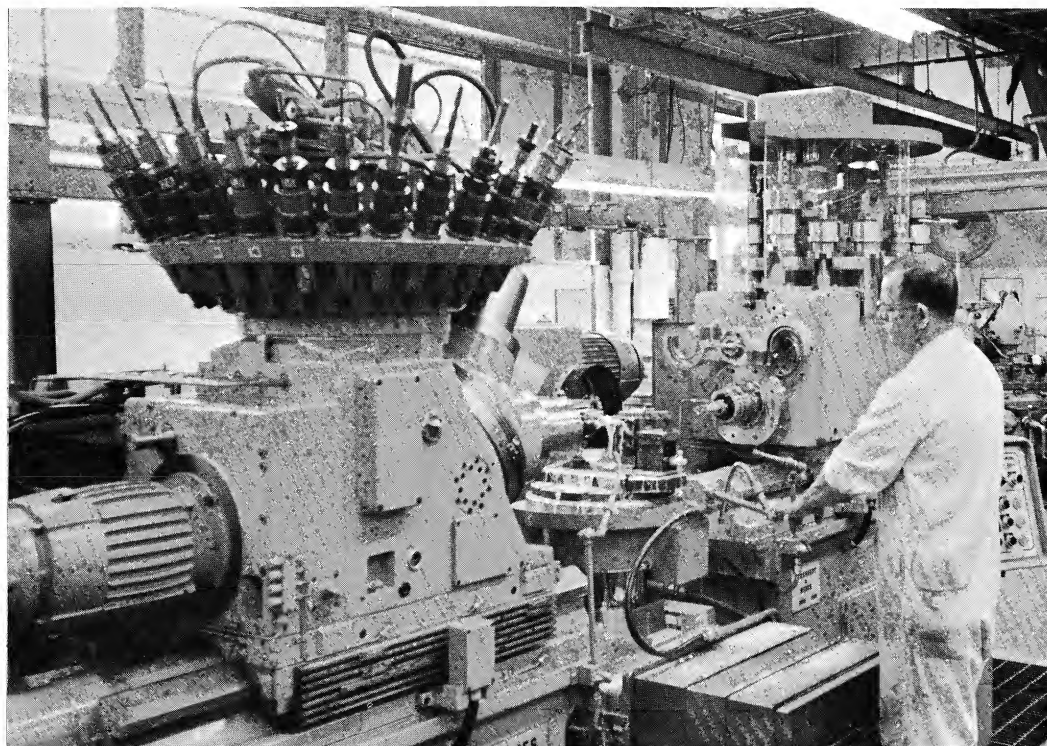
completely self-sufficient in this area. In the meantime, vendor service personnel are readily available should a serious problem arise.

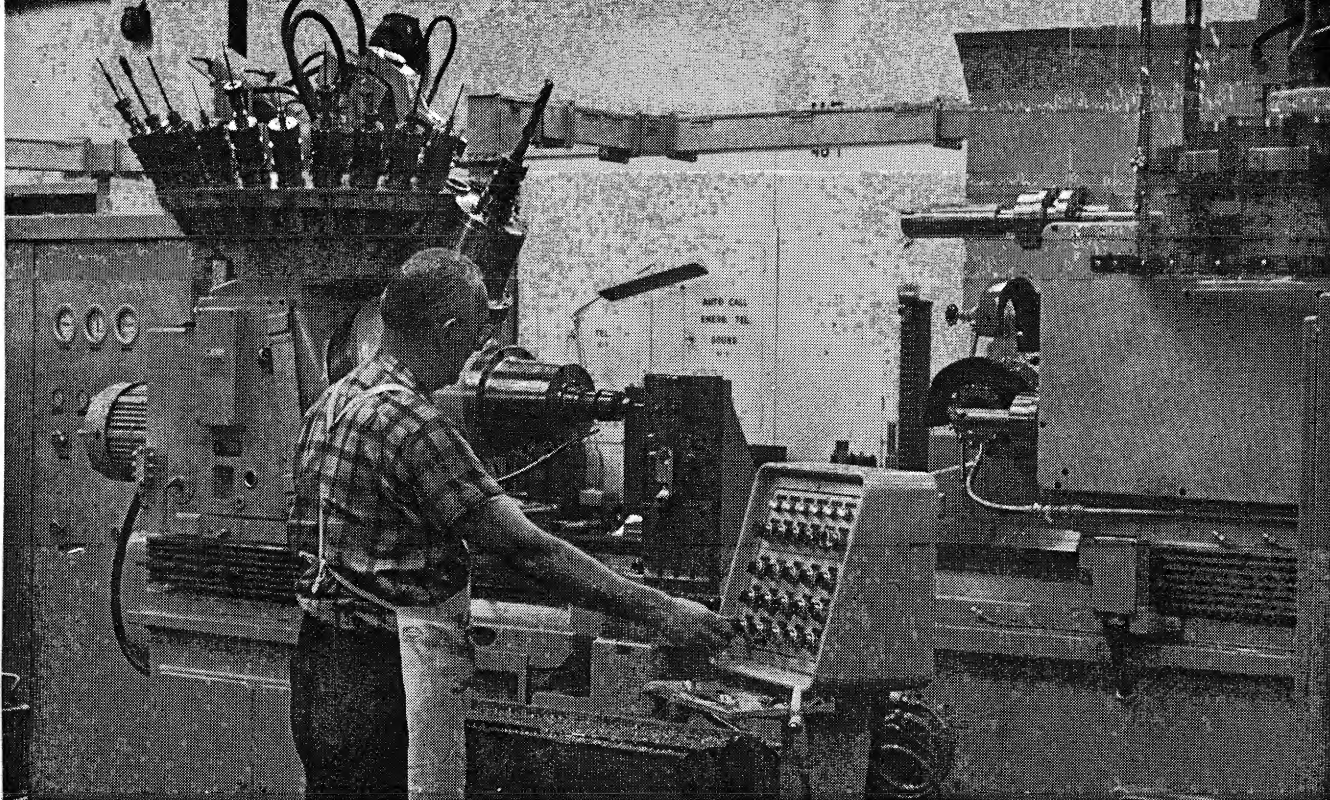
Tool Up By Degrees

To limit the initial expense for tooling, only those tools, holders, cutters, and adapters needed to handle the basic parts envisioned for the machine were selected. No attempt was made to buy perishable tools beyond immediate requirements. The general approach is to have sufficient tooling on hand to prepare the following job while a job is running. In coming months, it's planned to have enough tools on the shelf pre-set and stored for every standard job going across the machine.

In the area of preprogramming, of tool design and the tooling for several parts, initial thinking was concerned primarily with the need to move into production quickly. There was no time to go through a learning curve. Milton Roy now believes they should have requested that initial programming be limited to the acceptance part by the vendor. Added efforts would be done in-house since the company would be in a better position to know and understand its particular problems and how best to adjust to them.

The n/c project owes much of its success to enthusiastic teamwork displayed by Engineering and Manufacturing in their mutual desire to make the project "go". Most of all, management not only got on board to encourage the success of the enterprise but went out of its way to facilitate design changes to accommodate the product to n/c manufacture. ■





NC "machining center" contains universal head with tool changer (left), milling head (rear center) and boring head (right).

Metalworking's nc '63 Supplement

Multi-Purpose Machine — Job Shop in a Plant

Versatile "machining center" is paying for itself with savings in fixtures, inspection, scrap and machining time. Also, it's taking many expensive, one-shot jobs out of the model shop. Computer programming provides additional savings.

Numerical control achieves a long-standing goal of manufacturing engineers—completely machining a complex part with one setup on one machine under fully automatic control. Such a machine—an NC "machining center"—is providing spectacular advantages in machining precision castings at the Endicott, N. Y., plant of International Business Machines Corp.

After 5 months of two-shift operation with its new Hughes MT-3 "machining center" (the first unit purchased outside of the Hughes organization), IBM reports impressive savings in production time, tooling costs, inspection time and scrap.

Averaging results for the jobs run

to date, here is how the MT-3 is paying off:

- 50% reduction in floor-to-floor time
- 75% savings in fixture costs
- 50% savings in inspection costs
- Scrap and rework almost nil
- Fewer short runs in model shop.

About 10% of the parts being run on the Hughes MT-3 are completely machined in one setup from the as-cast condition. About 75% are machined completely in one setup after a preliminary skim cut on a conventional miller for fixturing.

Floor-to-floor time has been reduced by about one-half on the average job. This saving reflects: (a)

machining program controlled by tape—no time lost by the operator in checking machining instructions, blueprints, dimensions, etc., or positioning the work for each step in machining sequence; (b) automatic tool changing—the right tool is ready in the spindle when it's needed; (c) minimum of "cutting air"—tape enables cutters to approach work at maximum speed (150 ipm), then automatically decelerate at the minimum safe distance; (d) less handling time because of few setups.

Fewer setups mean fewer fixtures. Also, the fixtures that are employed are simpler and less expensive, since accurate tool positioning is provided by the control system rather than the fixturing.

Manufacturing engineer Arthur W. Camp, who has been closely associated with the MT-3, estimates that work-holding fixtures for the MT-3 cost at least 75% less than for conventional machine tools.

On five representative jobs, the

IBM's Vest-Pocket "Job Shop"

fixture costs for the MT-3 totalled \$6,110 compared with \$23,250 previously spent for conventional tooling. Mr. Camp points out that the figures for conventional tooling include only the cost of fabricating the fixture and that design time is charged to overhead. On the other hand, the fixture costs for the NC machine includes both fabrication and the cost of programming and preparing the control tape.

The parts being machined on the MT-3 are aluminum sand or die castings for brackets, supports, housings and similar structural parts for IBM computers, the main product of the Endicott plant. Lot sizes are relatively small: usually they range between 10 and 100 pieces; 50 pieces is typical.

Tolerances In Tenths

Machining tolerances are tight. In many parts bored holes must be within 2 tenths of size, distance between milled surfaces within 0.001 in. and hole locations within 3 tenths. Many of the critical dimensions are specified as statistical dimensions for statistical-quality-control purposes. This means that about 68% of the parts sampled must be within 50% of the allowable tolerance range.

IBM is finding that numerical control has reduced the size of the minimum economical production

run. One-shot jobs of about ten pieces used to be run off in the model shop if permanent tooling would be too costly. Today it pays IBM to route such one-shot jobs on the MT-3 if the lot size is only four or five pieces.

Another important area of savings is better quality and less scrap. IBM says that numerical control virtually eliminates the chance of scrap and rework once the control tape is proved out.

Savings in inspection time are another by-product of NC machining. Fewer parts need to be inspected to obtain assurance of accuracy and fewer dimensions need to be checked on the inspected parts.

On the average, IBM inspects about 50% fewer parts per lot with no loss in quality assurance. In cases requiring 100% inspection, the sampling rate could be cut by much more than 50%.

In addition, the number of dimensions checked on inspected parts has been drastically reduced. Usually, just a few controlling dimensions are checked to confirm that the part is acceptable. Inspection time on some parts has been cut from about 60 min to 10 min or less.

"Each time a piece is moved to another machine to continue the machining operation," Art Camp commented, "is another chance for scrap. If a piece can be completely ma-

chined in one fixturing, it becomes part of the machine. Dimensional relationships remain constant and a big source of scrap is eliminated."

Justified By Savings

The complete MT-3 center costs about \$235,000, including transportation, installation, training, tool holders and adapters. Can such an investment be justified? The answer, says IBM, is "Yes."

As a matter of policy the company does not disclose its specific criteria for justifying any capital investment. However, they do say that a plant that has the same cost structure, volume and quality requirements can expect the MT-3 to pay for itself in 2 to 5 years.

Furthermore, IBM applied their usual payback requirements to justify the MT-3. They made no exception to "get NC into the plant."

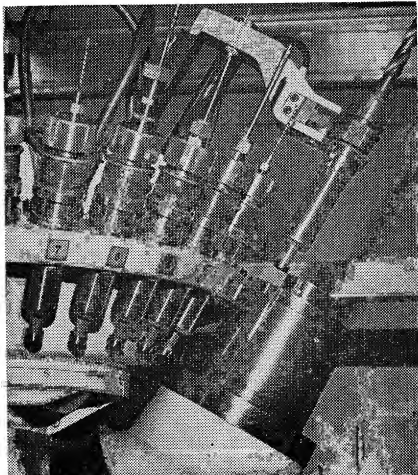
The MT-3 was justified on the basis of a two-shift utilization. It soon will be scheduled for three shifts, so that the payback period will be shortened proportionately.

The MT-3 machining center consists of a basic machine and control, with additional machining heads available as options.

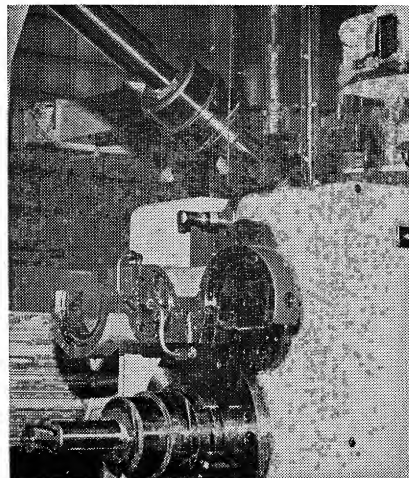
The basic elements are: (1) the universal head designed for drilling, tapping, light end milling and light boring (the head is equipped with an automatic tool changer and a magazine with a capacity for 30 tools); (2) the 18-in.-diam work table with controlled motions in the transverse and vertical axes and 16 rotary index positions; and (3) the Hughes NC solid-state positioning system that controls table and spindle motions, tool changing and all other machine functions.

IBM's version also has two additional machining units that are installed around the sides of the work table. One is a heavy-duty, 10-hp milling head with an 8-in. cutter capacity. The other is a 7.5-hp precision boring head with a 6-in. boring-bar capacity. The boring head is equipped with an automatic tool changer and a 14-tool magazine.

Tool changing is particularly fast



Next tool is loaded in idle spindle while other spindle is in cut. Spindles index.



Precision boring head has tool changer and magazine with 14-tool capacity.

because the magazine rides with the head and because of the two-spindle arrangement. No time is lost switching tools in and out of the magazine because the next tool is being loaded in the idle spindle while the alternate spindle is working.

Computer Programming

Control tapes for the MT-3 are now being programmed on a 1620 computer with the help of Autospot, a programming language developed by IBM for NC positioning systems.

"The difference between computer and manual programming," said manufacturing engineer William F. Henry, who used both methods, "is like night and day. Computer programming is not only faster but, because it eliminates many tedious calculations, it also greatly reduces the chance of error in preparing the machining instructions."

As an example of how Autospot simplifies the programmer's task, he cited a part whose original manual program had been rewritten by Autospot. The program took about 100 hr to prepare by manual calculation and contained 395 individual instructions. With Autospot, the same program required only 20 hr and contained only 51 instructions.

A detailed description of Autospot is available from IBM (also see *METALWORKING*, May, 1962), but here are a few of its advantages:

Programs proper machining conditions: For each tool called for in the machining program, from a master tool list in its memory the computer automatically furnishes the appropriate speed, feed and coolant instructions on the tape.

Clearance envelope: From the part and tooling drawings the programmer establishes an imaginary envelope around the part, outside of which the tool can move freely without danger of collision. For every motion, the computer figures how far the slide must retract so that the tool clears the perimeter of the envelope.

Rapid approach limit: The programmer specifies how far from the work (usually 0.1 in.) the slide should shift down from rapid traverse to feed. The computer automatically computes this point for each tool used.

Aside from the foregoing type of

"traffic" instructions, Autospot provides some invaluable short cuts for defining a series of positioning instructions. For example, to drill a bolt-hole circle, the programmer merely specifies the center, the radius, the number of holes and the angular spacing between holes (with skip-locations if any).

Repeat locations: If several operations are to be done at several locations (for example, drill, bore and ream six holes), the programmer writes their coordinate locations just once, and gives these locations a "Pattern Number." Thereafter he can program additional operations at this group of locations by calling for the appropriate pattern number.

Pocket milling: The programmer defines only the corners of the pocket, depth of pocket and number of steps-to-depth. The computer fills in the necessary positioning information to make the cutter machine out the pocket.

To use Autospot programming for the MT-3, IBM developed a post-processor routine. This routine is to be part of IBM's post-processor library and will be available to MT-3 users that have access to a 1620 computer.

Performance Test

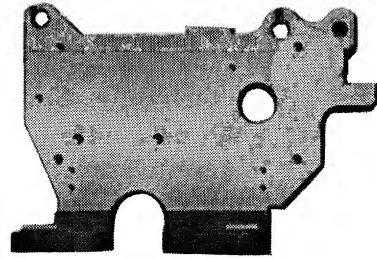
An interesting sidelight of the MT-3 installation is the special workpiece that IBM developed to test the performance of the machine. The test part is a hollow, rectangular aluminum casting measuring about 9 x 6 x 6 in.

The machining program uses 45 different tools. Except for some preliminary drilling, no tool is used twice in succession. This tests the accuracy of tool changing.

Locations of the bored holes are approached from different directions to test positioning accuracy.

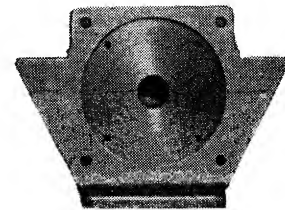
The heavy-duty milling head is programmed to remove $\frac{3}{8}$ in. of stock in one pass to check the system at full-rated power. Also adjoining portions on the same surface are milled to the same depth with one heavy cut on one side and a succession of light cuts on the other. This checks the spindle's depth positioning and traversing accuracy under different loads. In all, the test machining tape contains 540 blocks of instructions.

Three Typical Parts



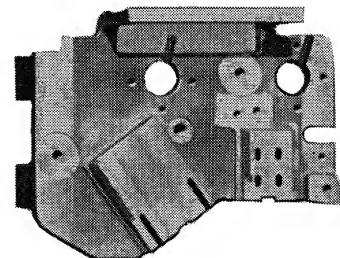
Carriage Support

	MT-3	Model Shop	Conv'l
Mach. time, hr/pc	0.39	7.8	0.91
Tooling cost	\$1,290	—	\$5,200



Mounting Bar Support

	MT-3	Model Shop	Conv'l
Mach. time, hr/pc	0.42	10.7	0.71
Tooling cost	\$1,550	—	\$8,250



Retractable Head Platform

	MT-3	Model Shop	Conv'l
Mach. time, hr/pc	1.1	23.6	yearly quantity does not justify tooling
Tooling cost	\$6,620	—	

NC makes major savings in machine time and tooling costs over conventional machining, big time savings over model shop. Note job that couldn't justify permanent tooling. NC tooling costs include fabrication plus programming, conventional tooling, fabrication only.

The Hughes MT-3 Machining Center: the most important advance in metalworking in over a decade!

The numerically-controlled MT-3 is the most productive machining center in the world. There are no design compromises—all components and subsystems are designed to keep the cutting tools engaged at optimum efficiency. It is the only multi-operation machine that gives you these major productivity and performance features:

Productivity

- Automatic tool changes in less than 3 seconds.
- Permits use of 45 different tools in one setup.
- Building-block design allows purchase of only the components or capabilities needed; additional work heads may be added later as required.
- Separate work heads provide optimum metal cutting conditions; no compromises as with multi-function head. (The Universal head features high-speed tool changing; minimum tool holder inventories. The milling head features a heavy-duty 10 hp milling spindle; up to 8-inch cutter. The precision boring head provides precision boring to 0.0002" diametral accuracy with intermediate tool

changes; and radial orientation of tools, with a capacity to 6 inches in diameter.)

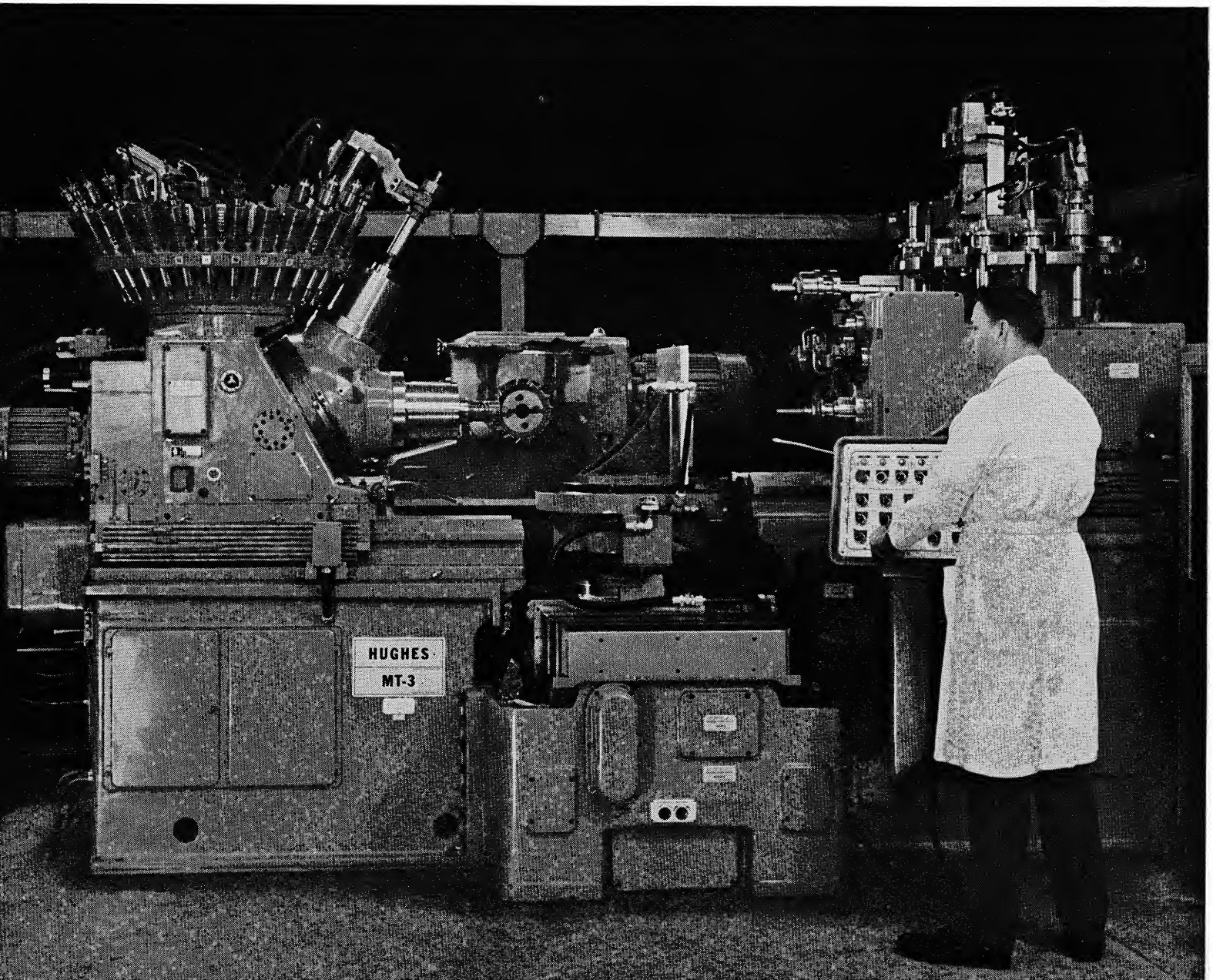
Performance

- Temperature control maintains dimensional stability of entire system.
- Positive drive to all tools.
- Advanced incremental programming techniques, using E. I. A. data coding.
- Reliable Hughes solid-state electronic control.
- Automatic tapping cycle provides precision threads from 0-80 to 1"-8.
- Single source responsibility.

The Hughes MT-3 will drastically reduce your current manufacturing costs, whether you are using conventional methods or numerical control. Proof? Send a typical part drawing for a production time estimate or write for complete specifications to Hughes Industrial Systems Division, Marketing Department 92-21-A, P. O. Box 90904, Los Angeles 9, Calif. Or circle 525 on reader service card.

HUGHES

HUGHES AIRCRAFT COMPANY
INDUSTRIAL SYSTEMS DIVISION



Job Shop Within a Shop

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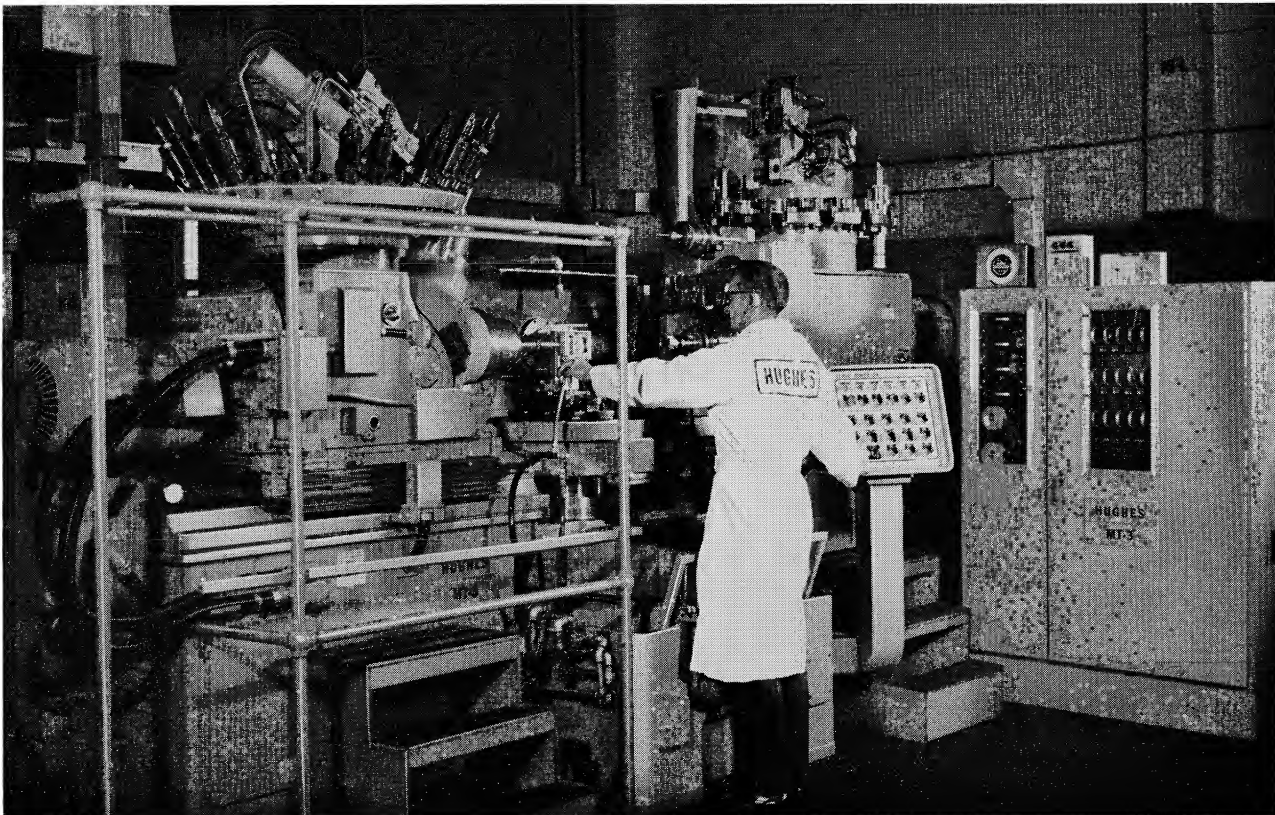
An ideal job shop is one capable of turning out small lots of a wide variety of complex parts at low cost in minimum time. Experience at Hughes Aircraft Co. and elsewhere has shown that its Industrial Systems Division Model MT-3 machining center in many

ways meets this definition. In effect, the numerically controlled MT-3 shown in the heading illustration has been found to be "a job shop within a shop" for a broad range of application.

Basically, the MT-3 machining center produces finished parts

ready for the assembly line from a programmed tape or a blueprint. It is equipped with a rotary work-table (center, Fig. 1) and a universal head (Fig. 2) with a dual-spindle indexing turret and a thirty-tool capacity changer.

Two additional optional build-



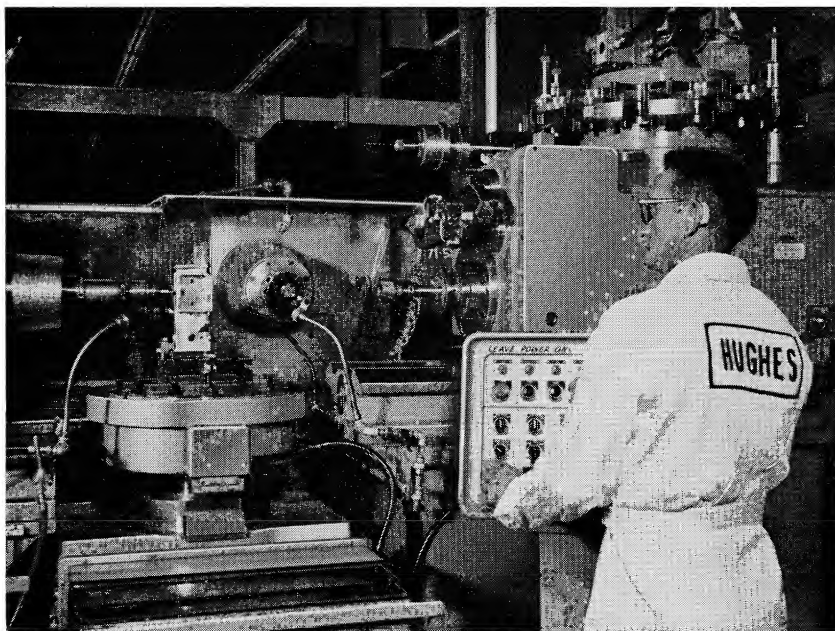


Fig. 1. Close-up view of work area of MT-3 numerically controlled machining center. Part on rotary indexing table is being machined by tool in the universal spindle head at right. Tape program includes operations by heavy-duty milling head at rear and precision boring head at left.

ing-block elements, a heavy-duty milling head and a precision boring head with a fourteen-tool capacity changer, provide for a large number and a wide range of operations on a part. These heads are seen close up at the rear and right of the work-table in Fig. 1. Operations that can be performed automatically in one setup include heavy and light milling, drilling, boring, tapping, and reaming.

Typical parts being produced on the MT-3 by Hughes Aircraft Co., often at manufacturing cost savings ranging from 50 to 75 per cent, are shown in Figs. 3 to 6. In many cases, despite a large number of operations, only a single setup is required. Simple holding fixtures replace the complex tooling ordinarily required and tolerances of a few ten-thousandths of an inch are regularly obtained.

To further reduce fixture preparation time and costs, Wharton tool elements are often used. When machining the complex bracket shown in Fig. 3, Wharton elements are used exclusively, cutting the required tool preparation time to only fifty hours. For conventional machining, 1020 man-hours would be consumed in building the twenty-eight tem-

plates and twelve drill jigs required to handle the work.

These brackets are made in ten different variations with changes in over-all length and hole patterns. Although three setups are employed for each part, only three Wharton fixtures are needed to machine all ten different brackets.

The fewer setups and simplified

fixtures used permit setup operations to be performed in four and one-half hours instead of the twenty-two hours required to set up for conventional machining.

Except for one honing operation, these parts are produced complete to blueprint sizes in three numerically controlled operations. Over 90 per cent of the part, by weight, is removed in machining the brackets from the raw material.

Since three tapes are needed for each of the ten bracket configurations, thirty individual programs and tapes must be prepared. All three heads of the MT-3 and thirty tools are employed to produce the brackets in an over-all seventy-six-minute machining cycle. Estimated time for conventional machining is four hours. Planning, tooling, and preparing the thirty programs and tapes for the ten brackets required 298 hours, in comparison to 1080 hours for planning and tooling for

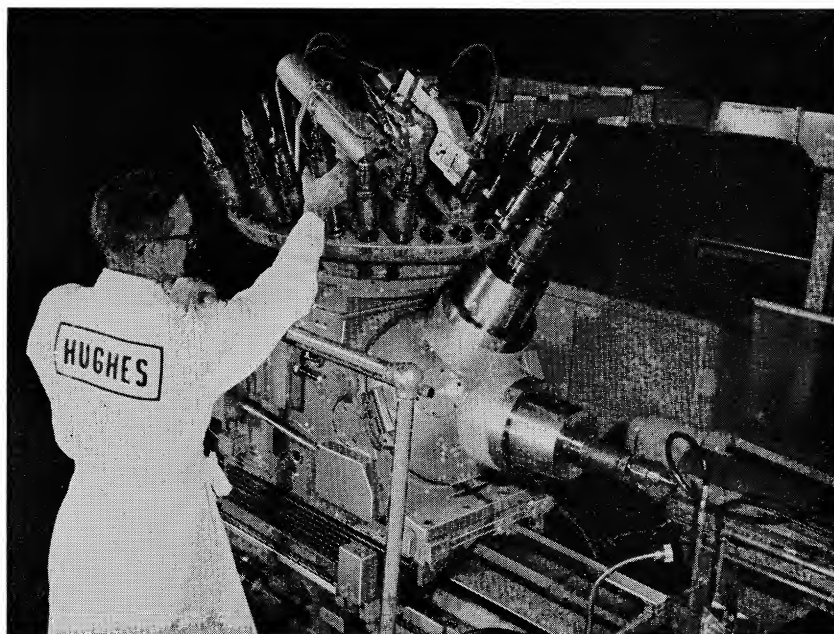


Fig. 2. The universal head is equipped with a double-spindle turret and a thirty-tool capacity changer. While one spindle is operating, the cutter in the idle spindle is changed for subsequent use in the machining cycle.

machining the same parts conventionally.

The first tape is programmed to rough-mill all surfaces and windows, allowing 0.030 inch per side for finishing cuts. These operations remove almost 80 per cent of the work-piece material in a twenty-minute cycle.

In the second setup, three sides, a large window, and an inner pocket are finish-milled; eight holes are drilled, four reamed and four countersunk; and chamfers are cut on the outer periphery. This cycle removes another 6 per cent of the original material and requires about eighteen minutes. The third tape directs the finish milling of four outer surfaces, the inner contour, three pockets, and a small tab. In addition, eight holes are drilled, two bored, one counterbored, and one reamed.

The complex antenna mount, shown in Fig. 6, is also machined by Hughes on the MT-3. Nineteen surfaces are milled at various levels on six sides of the part. In addition, sixty-one holes are center-drilled and drilled, forty of which are counterbored and thirty-two tapped. These operations are performed in two setups requiring two tapes and two holding fixtures. Nineteen cutting tools are used in the universal head and five in the precision boring head.

Planning, programming, and tooling preparation to implement the numerically controlled machining center for this part required 848 hours. This can be compared against 1732 hours for planning and tooling of the same part for conventional machining. Setup time and machining time for MT-3 are three hours and twenty hours, respectively. On conventional equipment, these parts were set up in twenty hours and machined in 6.4 hours.

A single tape and holding fixture are all that is needed to perform fifteen operations on the hose coupling illustrated in Fig. 5. Milling, boring, drilling, and tapping are performed, using only the universal and milling heads. The part is completely machined (except for deburring) in ten minutes, approximately one-fifth the time required for conventional

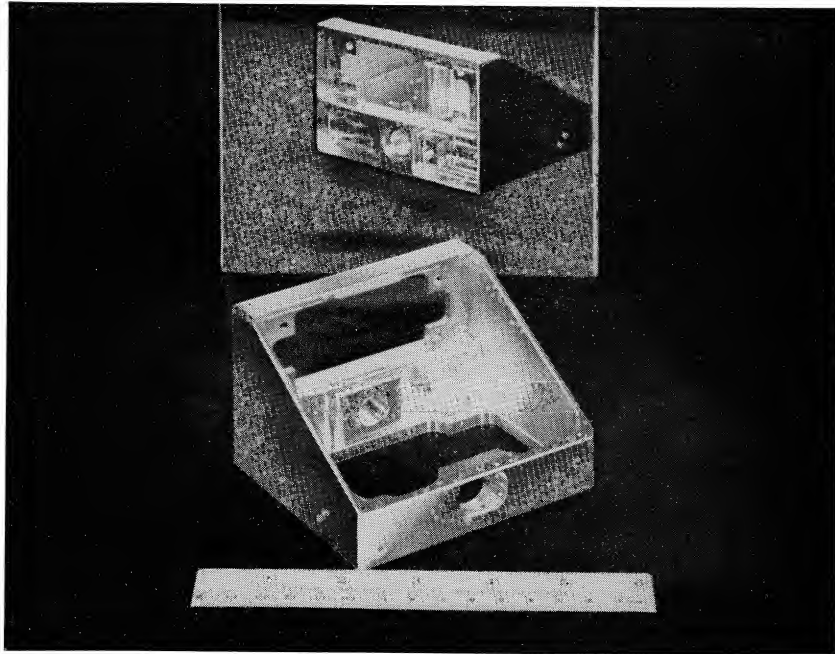


Fig. 3. Only three work-holding fixtures are required to produce ten variations of these brackets. Each part is machined in three setups using three tape programs. Over 90 per cent of original part material is removed in a total machining time of seventy-six minutes.

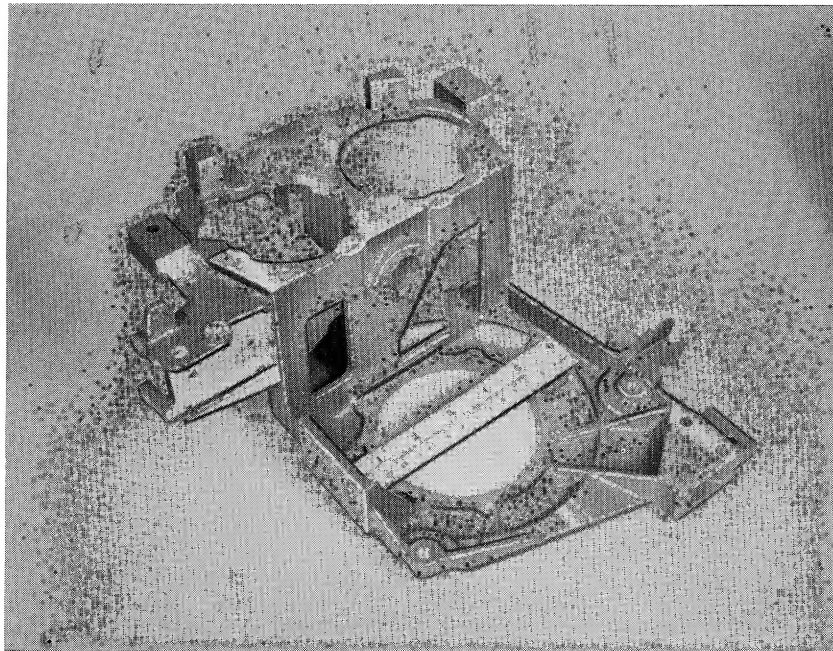


Fig. 4. Complex antenna mount machined using two setups and two tapes. Sixty-one holes are centered and drilled, forty are counterbored, and thirty-two tapped. Nineteen surfaces are also milled. Machining time is eighty-one minutes.

machining. Planning and preparation of tooling, program, and tape were accomplished in eighty-two hours, about one-quarter of the time necessary for tooling and planning for machining the part on standard drilling and milling equipment.

The end block shown in Fig. 6

is completed on the MT-3, except for one tapping and three milling operations. One Wharton holding fixture is used and a single tape program directs machining of the part in twelve minutes. Setup is done in two and one-half hours. Implementation for numerical-control machining required only

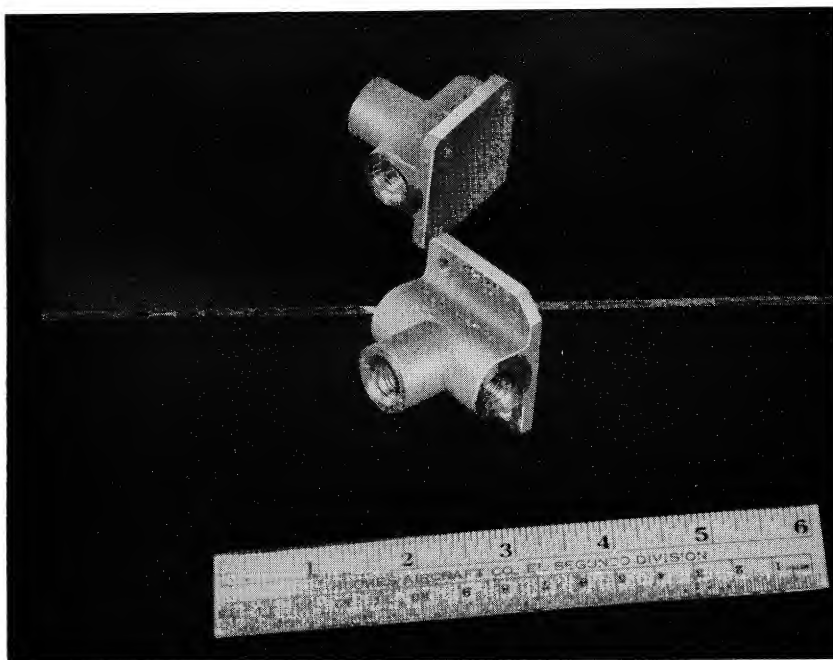


Fig. 5. Only the milling and universal heads are used to complete this component in a single setup. Implementation for numerical-control machining required only one-fourth the man-hours necessary to plan and tool conventional equipment for the part.

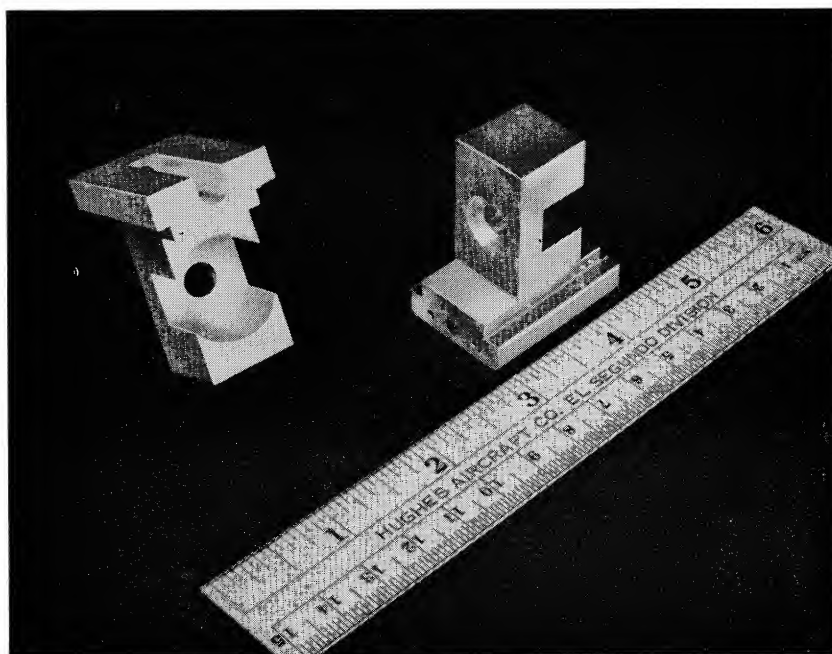


Fig. 6. Another component machined in a single tape program on the MT-3 machining center. Substantial time savings were experienced in actual machining, setup, and overall implementation.

thirty-eight hours. In comparison, planning and tooling for conventional operations took sixty hours, setup required six and one-half hours, and actual machining, fifty minutes. As in the other examples, the time saved in planning and tooling for numerical-control production more than offsets that ex-

pendent in programming and tape preparation.

The Hughes-designed electronic control system, which incorporates solid-state control circuits and data-handling techniques, is a digital system using incremental planning. It employs E.I.A. (Electronic Industries Association) data

coding and uses standard 1-inch wide, eight-channel punched tape.

The photoelectric reader operates at speeds of 200 rows per second, and data-handling time is 0.3 second per block. This eliminates the need for buffer storage equipment. The system is capable of controlling all optional heads, which include a multiple-spindle drill head that will drill up to ten holes at a time for high-production setups.

Simplified programming can be accomplished manually from a "manuscript" prepared from the parts drawing, or computer programming can be used. A special block code is employed which permits tool adjustments to be made during operating cycles.

The machine can be operated manually, semiautomatically, or automatically. In manual operation, all machine movements are initiated at the control panel and the keyboard input on the electronic control unit. In semiautomatic operation, the operator retains control of tape reading and initiation of axes movements, while visual displays allow complete verification of data input to the system. When operated automatically, it is under full tape control, with provisions for the operator to override commands from the tape.

Arrangement of the spindle heads around the work-piece makes it possible to use any one head while another is being made ready. Thirty-one feeds can vary the feed rate of the cutting heads or the work-table from 1 to 75 ipm. A 150-ipm tool approach and retraction rate is maintained until the cutter is ready to enter the work, or has reached its "homing" position.

Although primary advantages of the MT-3 have been found to be in the reduction of tooling and machining costs, other benefits are obtained. These include (1) reduced lead time to produce the first component, (2) smaller in-process parts inventory, (3) minimized parts handling, (4) lower inspection and quality-control costs, and (5) improved management control over the manufacturing process.